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The MAGIC of Clouds

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The latest reports from the Intergovernmental Panel on Climate Change (IPCC) have reiterated that clouds remain the largest source of uncertainty in current climate projections. Boundary layer clouds (i.e. those within the atmospheric turbulent layer adjacent to the surface – roughly 1 km deep) have a particularly important role on the overall climate system due to their complex interactions with radiation, precipitation, and surface fluxes. Stratocumulus cloud decks – which are often found off the west coast of continents – with their high albedo and large horizontal extent, transition to a cumulus regime as the boundary layer advects over warmer waters along the trade-winds towards the equator. From a large scale perspective, cumulus cloud cover is small, and although cumulus clouds play a crucial role in atmospheric vertical transport (and in modulating surface evaporation), their overall interaction with radiation is not large. This key cloud transition between these fundamental regimes – from stratocumulus to cumulus – plays an important role in cloud-climate feedbacks. However, the physical mechanisms responsible for the transition are not fully understood and in particular current climate and weather models fail to reproduce many of the key properties of the stratocumulus-to-cumulus cloud transition (e.g. *Teixeira et al.*, 2011).

The particular transition from stratocumulus to cumulus that occurs over the North-Eastern Pacific, as the air flows from California towards Hawaii, is, because of the size of the ocean basin and the shape of the adjacent continents, arguably the most 'pure' version of the transition. This transition was investigated in *Teixeira et al.* (2011) by evaluating a variety of weather and climate models against satellite observations along a representative cross-section, the GPCI transect (Fig. 1), which extends from the coast of California southwest to the equator (GPCI stands for the GCSS Pacific Cross-section Intercomparison, where GCSS is the GEWEX Cloud System Studies, and GEWEX is the Global Water and Energy Exchanges Project of the World Climate Research Programme). This study helped characterize the main deficiencies of models in representing this transition, but did not allow for a detailed understanding of the physics involved. In order to achieve this goal, dedicated high-resolution modeling, such as with LES (Large-Eddy Simulation) models, and in-situ observations of the cloud transition are necessary.

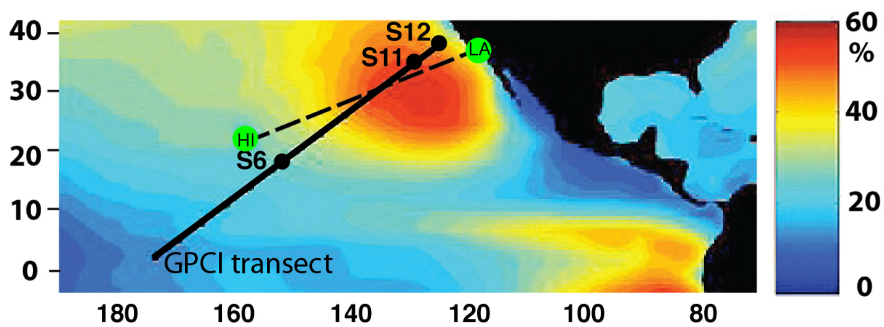

Fig. 1. Average June-July-August low level cloud cover from ISCCP (International Satellite Cloud Climatology Project), with GPCI transect (solid) and MAGIC route (dashed) between Los Angeles to Honolulu. Points S6, S11, and S12 used in CGILS (Cloud Feedback Model Intercomparison Project (CFMIP)-GCSS Intercomparison of Large-Eddy and Single-Column Models) are also shown. Based on *Teixeira et al.* (2011).

The MAGIC (Marine ARM GPCI Investigation of Clouds) deployment, supported and operated by the Atmospheric Radiation Measurement (ARM) Climate Research Facility of the US Department of Energy, is a unique field campaign dedicated to observe the stratocumulus-to-cumulus cloud transition over a significantly long period of time. The MAGIC approach took advantage of the mobile nature of the Second ARM Mobile Facility (AMF2) by deploying its suite of instruments on board the Horizon Lines cargo container ship *Spirit* (Fig. 2) as it plied its regular route between Los Angeles and Honolulu from September 2012 to October 2013. This route transects the cloud regimes mentioned above that exert a large influence on Earth's climate and are of great interest to climate modelers, and it lies near the GPCI transect. The clouds are primarily stratocumulus near the coast of California and transition to trade-wind cumulus near Hawaii.

Fig. 2. Horizon *Spirit*. All AMF2 instruments and operations during MAGIC were on the bridge deck, which is near the mast at the front of the ship. The stacks are the white objects approximately two-thirds from the front to the back of the ship. Photograph by Dennis Shum.

The AMF2 consists of three twenty-foot cargo containers containing instruments, computers, and supplies. During MAGIC, three radars, two lidars, two microwave radiometers, a ceilometer, a total sky imager, disdrometers, and other instruments were used to measure properties of clouds and precipitation. A suite of instruments measured direct and diffuse incoming radiation, both spectrally and broadband. Other instrumentation measured key aerosol properties such as concentrations of condensation nuclei (CN), concentrations of cloud condensation nuclei (CCN) at various relative humidities, size distributions, light scattering and absorption at multiple wavelengths, and hygroscopicity. Additionally, aerosol samples were collected for later analysis of bulk and individual particle composition, individual particle morphology, and ice nucleating ability. Basic meteorological quantities and sea surface temperature were also measured, allowing computation of surface energy fluxes. Radiosondes were launched with weather balloons every six hours (every three hours for the period of July 6-18, 2013) to provide information on atmospheric vertical structure. More than 550 successful radiosonde launches were completed. Two technicians were on board during the entire deployment, and often one or more scientists rode the ship for a round trip. In total, MAGIC consisted of nearly twenty round trips and 200 days at sea, yielding an unprecedented data set over a region that is vastly undersampled. The data are being ingested and deposited in the ARM data archive (www.archive.arm.gov) where they are available to all.

The First MAGIC Science Workshop was held May 5-7, 2014 at Brookhaven National Laboratory on Long Island, NY to present the status of MAGIC activities, allow investigators to present preliminary results, determine what topics require attention in order to move forward with model intercomparisons or other analyses, establish networking and collaborative possibilities, and discuss future MAGIC activities. The meeting was well attended, with around 40 physical attendees and another dozen who attended remotely using Skype. The keynote address by Chris Bretherton (University of Washington), "The Science of the Stratocumulus-to-Cumulus Transition," gave a comprehensive history of measurements and attempts to understand this transition, and an excellent summary of our current knowledge and of what topics need to be addressed to further this knowledge. The workshop had a variety of sessions including on (i) the history and summary of the MAGIC deployment; (ii) MAGIC observations and data; (iii) MAGIC science (e.g. science questions that have been, can be, or will be addressed with MAGIC data); and (iv) future directions and plans. The workshop agenda with links to the presentations is available at http://www.bnl.gov/envsci/ARM/MAGIC/workshop/agenda.htm.

The MAGIC experiment created an unprecedented observational dataset due to its temporal and spatial sampling of the marine boundary layer as it flows from the cold waters off California to the warmer waters around Hawaii. MAGIC data has the potential to lead to a deeper understanding of the physics of the stratocumulus-to-cumulus cloud transition and to the accurate representation of this transition in future weather and climate models.

For more information on MAGIC, or to be included on the MAGIC Science News distribution list, please contact Ernie Lewis at elewis@bnl.gov, or visit the MAGIC websites at http://www.arm.gov/campaigns/amf2012magic and http://www.bnl.gov/envsci/ARM/MAGIC/.

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